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The Pilot Digital Operations (PDO) project is an investigation by the Defense Mapping Agency (DMA) into the practicality and utility of computer mapping. PDO is a set of experiments whose results will be used to help in the evaluation of the feasibility and desirability of performing the MC&G production operations in the digital domain. The importance of this effort is based on the nature of future mapping sources, the desire to automate, as much as possible, the production operations and the basic trends of forthcoming technology. The experiments OVER

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20. ABSTRACT (Continued from other side)

are meant to test available "off-the-shelf" technology. By assessing the current state-of-the-art, DMA can determine what areas require further R&D and what are the risks associated with a digital production system. The early experiments test some basic classes of image processing algorithms. The next set test MC&G production functions. This leads to an experiment which involves actually generating a DMA product. Other experiments deal with general design issues emphasizing the human factors and data base aspects of the problems. PDO is scheduled to be completed by the end of 1982. The results to date are discussed and a brief description of the remaining experiments is given.

The Defense Mapping Agency's Pilot

Digital Operations

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The Defense Mapping Agency's Pilot Digital Operations

Introduction

The Defense Mapping Agency's (DMA) mission is to provide the Department of
Defense and the merchant marine with Mapping, Charting and Geodeitv (MC&G)
products and services. Over the last decade, DMA's product line has
dramatically expanded to include digital products in support of training
simulators and advanced weapon systems. This additional requirement has
only been accomodated through a coninuing program of innovation and a
furthering of the state of the art.

DMA is actively investigating a digital production system. One of the
motivations is the increasing percentage of the work load which is devoted
to digital products. Secondly, there is a trend for source material to be
collected and disseminated in a digital form. Thirdly, digital technology
is still rapidly advancing while optical technology is relatively mature.
Finally, if any break throughs occur in automating image interpretation
functions, these will require complex algorithms which will probably only
be implementable using digital methods.

The Pilot Digital Operations (PDO) project is an investigation by DMA into
the practicality and utility of digital techniques for use in MC&G production
processes. PDO consists of a set of experiments whose results will be used to
help in the evaluation of the feasibility and desirability of performing the MC&G
production operations in the digital domain. Other benefits include technology
transfer, scientific results which can be used to support design decisions for
prototype digital systems, and an identification of areas requiring further
research and development.

History of PDO

PDO started in 1976 with a basic systems concept formulation. This was not an attempt to design the ultimate digital system, which would have been premature, but was only to provide a frame work for the rest of the project. This frame work identified applicable required technologies and a state of the art survey was performed. Based on these surveys, the existing systems, hardware, algorithms and methods which merited further testing were identified. Test plans were developed for experiments which would examine existing technology as it could be applied to the MC&G production problem. The experiments were designed to involve DMA personnel to the maximum extent possible. A large part of the testing is being done at the Engineering Topographic Laboratory and at an experimental facility in DMA. Support was also received from the Rome Air Development Center and contracts have been negotiated with both commercial and academic institutions to test specific systems and algorithms. The management of the effort involves a PDO chief at each production center and headquarters. Reporting is directly to the top management of DMA.

There are four types of experiments in PDO. The basic operations functions consists of classes of image processing algorithms and automated techniques. The following are the experiments in this catagory:

- o Image Enhancement

- o Temporal Image Normalization

- o Image Correlation

- o Image Mensuration and Transfer

- o Change Detection

- o Data Compression/Decompression

- o Pattern Recognition

There are three experiments which deal with trying to perform major MC&G production processes. They will draw on the basic operations functions experiments and will use the most promising algorithms and techniques. These experiments are:

- o Screening and Assessment

- o Interactive Feature Extraction and Analysis

- o Digital Photogrametry

The experiments proceed logically from basic operatons to MC&G functions to an experiment to produce a portion of a standard DMA product. The fourth experiment deals with support type considerations. This is the human factors experiment. All experiments will be completed by December 1982.

<div align="center">Completed Experiments</div>

Image Enhancements

The primary objective of the Image Enhancement experiment was to review development efforts performed by government, industry, and academia in digital image enhancements and to select a sampling of these techniques that would best support the other activities within the PDO Program. The experiment was to evaluate these digital image enhancement methods and develop a fundamental library for subsequent use in other PDO experiments; e.g., Feature Analysis, Digital Mensuration, Change Detection, and others. The enhancements were divided into five classes of operations and a set of candidate techniques chosen for each class. The five classes of operations were: Gray Scale, Noise Supression, Resampling and Edge Enhancements, and Edge Detection.

Software was developed by DMA technical personnel and implemented on the U.S. Army Engineering Topographic Laboratory's Experimental Digital Interactive

Facility. Objective and subjective tests were conducted and from the test data a fundamental library was chosen containing 21 image enhancement techniques for use by the other DMA PDO experimenters.

The evaluation method used was both objective and subjective testing. Objective testing data was divided into four types; (1) hardware/software, (2) operation, (3) input/output image, and (4) artifact. While all four types of objective testing data is important to the overall objective evaluation, the artifact data is the most significant of the objective data types. In the context of this experiment, an image artifact is defined to be any undesired distortion to image structure caused by digital processing. Since artifact distortions in MC&G enhanced images can introduce interpretation and mensuration errors in subsequent analysis, the discovery and elimination of digital artifacts is most important. The criteria adopted for subjective evaluation of data was in terms of cartogrpahic interpretability. This is how well can a cartographer complete his task of feature analysis using digital image interpretation. The typical feature analysis functions are detection, identification, class-ification and delineation; delineation was not a consideration in the subjective evaluation.

The results of the objective and subjective evaluation are documented in tables within the report. Briefly, in the objective tests, artifact distortions caused by noise suppressiion and edge sharpening enhancements were detected by applying the enhancements to the two test patterns. The enhanced test images were examined for either line or edge artifacts. Each detected artifact was further classified by type, direction, and strength. Artifact distortions caused by gray scale and resampling enhancements were not detected through the use of test patterns but by observation of unnatural structure in the

enhanced test images. Although these artifacts were not tested for specifically, they were documented by the experiments when observed. A listing of the enhancement artifacts is provided in the report.

The evaluation of the subjective test data is based on psychometric statistical analysis. Psychometric methods allow one to statistically quantify subjective data. A psychometric interval scale for each candidate enhancement group was developed to determine both the order of the enhancements within a group (from best to worst) and the magnitude of the differences between the enhancements. Tables and images of each of the seven groups is provided in the PDO Digital Image Enhancement Report.

We believe this experiment to be a great success to DMA not only from the viewpoint of use by other PDO experimenters, but provided insight into the effects of various enhancement routines in aiding man and machine in doing its respective job.

Image Mensuration and Transfer

The objective of the Image Mensuration and Transfer experiment was to evaluate feasiblity and practicality of using soft copy imagery for the functions of point transfer and stereoscopic mensuration of MC&G features. To perform this evaluation a comparison between known film methods and unknown soft copy/digital methods was made.

The imagery used in the experiment represented, to a degree, a cross-section of sensor configurations used at DMA and a variety of temporal conditions, terrain/cultural contracts and MC&G feature/point types. The imagery was, however, "clean" in that it was near vertical and with average density and

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resolution. The soft copy mensuration portion of the experiment was conducted

on the U.S. Army Engineering Topogrpahic Laboraotry's Experiment Digital Interactive

Facility while the hardcopy mensuration was performed on OMI Nistri TA3PM

Stereocomparator at DMA Aerospace Center. The test imagery was absolutely

oriented for purposes of image and object space comparison of film to digital

measurement methods. Some software modifications were made to the USAETL

system to allow the testers to perform the test in a scenario closely approximating

the present production procedures. DMA personnel made all software modifications

and developed the testing procedures.

The test procedures were based on the selection of digitized subsets/subimage

areas from controlled photogrpahic models. Thirty-six film images containing

eighty/MC&G features were digitized and measured. Each point was measured

repeatedly to allow for statistical estimates of mensuration precision.

Hardcopy measurements were accomplished stereoscopically or monoscopically

on the panchromatic image that was digitized for soft copy measurements.

The softcopy measurements were collected stereoscopically using the

anaglyphic method available on the USAETL System. The data was transformed

from digital to metric format and was processed using DMA analytical

photogrammetric software.

Detailed subjective and objective results were derived and are tabulated

in the DMA Image Mensuration and Transfer PDO Report. It was demonstrated

by this test that softcopy mensuration is feasible and affords acceptable

precision. A valuable derivative from this experiment was the development

of a cadre of individuals with a considerable level of proficiency with

digital image methods and technologies. In general, the results show that

monsocopic and stereocoopic measurements on hardcopy and softcopy imagery

used in this test were within expected accuracies. Anaglyphic stereo methods caused mensuration constraints and are not recommended for future digital image mensuration devices (a follow-on experiment "Digital Photogrammetry" will evaluate anaglyph versus optical digital stereo mensuration mehtods in greater details). The pixel size of the digitized image (12 micrometers) was a limiting factor in the hardcopy versus softcopy mensuration accuracy comparison. The storage capabilities and visual displays available for use in this experiment would preclude the practicality of all-digital production systems for most MC&G mensuration related tasks, however, this is not to imply that other current state-of-the-art systems would not meet those requirements.

The results of this experiment have been instrumental in formulating requirements for future digital image exploitation systems and provided valuable insight into the follow-on PDO experiment in Digital Photogrammetry.

Data Compression/Decompression

The application of digital image processing techniques to the production of DMA MC&G products will require the transmission, storage, and mainpulation of of digital images. The number of bits required to encode a typical set of imagery that covers a typical geographical work area for one operator is estimated to be 1.6×10^{10}. This does not include the other knowledge required to support an image analysis function. It is estimated that an additional 10^{10} bits of information will be required. Storage and data structures become an important issue to DMA if DMA is to have an all digital production system at some point in the future.

The purpose of the compression/decompression experiment was to address the storage issue and the associated issue of how algorithm (digital image correlation) performance is degraded by imagery which has been degraded by a compression/decompression (C/D) process.

Initial test and evaluation computer experiments with Differential Pulse Code Modulation, Huffman Coding, Fast Fourier Transform, Fast Cosine Transform, Entropy, Autocorrelation, and Historgram techniques were conducted. Mathematical models for these techniques were developed, implemented and tested with simulated data. Three of these methods were chosen for further testing:

- o Differential Pulse Code Modulation (DPCM)
- o Fast Fourier Transform (FFT)
- o Discrete Cosine Transform (DCT)

The original input images for the rest of the experiment formed one stereopair of conventional black and white photographs. Thirty decompressed images were obtained by processing each of the input images through each of the C/D algorithms five times. In each of the five cases, the number of encoding bits per pixel varied.

The test data collected for each of the thirty decompressed images consisted of the measures of entropy, measures of degradation, and measures of the effects of decompressed images on digital image correlation. In theory at least, entropy is the measure of the average number of bits per pixel necessary to encode an image without loss of information. The technique used in the experiments for measuring the degradation associated with a decompressed image is based on the statistical analysis of the residual image. The residual image consists of the difference between the gray levels of the original image and the corresponding gray levels of the decompressed image. The entropy of the residual image, the mean residual, and standard deviation of the residuals constitute the measures of degration.

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To measure the effects of degradation, each decompressed stereo-pair was tested with respect to a digital image correlation algorithm. The computer image correlation algorithm locates and computes the image coordinates of control proints. A measure of the effects of degradation was obtained by comparing the image coordinates of the control points on decompressed images with the coordinates of the control points on the original input image.

The results of testing and evaluating entropy algorithms indicate that obtaining an accurate measure of entropy will provie expensive in a serial computational environment; and the hope of having computer automatic selection of an appropriate C/D algroithm based on entropy was found to be impractical. The success of image correlation depends on the uniqueness of the gray level texture in the areas correlated and performance is not necessarily affected by degradation due to C/D processes.

The Discrete Cosine Transform was the best C/D technique tested. Some feature Analysis processes may not be affected by degradations attributed to C/D processes. Further test and evaluation with respect to a variety of images and Feature Analysis processes, is required. It does appear that the selection of a C/D algorithm and the degree of compression may have to be done by subjective evaluation for each MC&G function. An automatic method using some easily computed statisitc is not currently available.

On Going Experiments

Automated Pattern Recognition: The Automated Pattern Recognition experiment is evaluating seven pattern recognition algorithms that have been developed in the academic community and represent state-of-the-art development and based on DMA review show promise of application toward classifying MC&G features and represent different approaches to the task.

The seven universities have completed their work and have provided their results for evaluation. The evaluation shall be by comparison of classification results from the automated method against classification using manual methods.

Results are planned to be published in mid-1982. A selection of three of the algorithms is planned for installation on DMA Remote Work Processing Facilities (RWPF) at DMA Aerospace Center and DMA Hydrographic/Topographic Center for further evaluation as part of a follow-on PDO experiment in Feature Analysis.

Feature Analysis

The Feature Analysis experiment is to evaluate feasibility and practicality of using automated pattern recognition algorithms in conjunction with interactive digital image processing to do the functions of feature analysis. The DMA Remote Work Processing Facility (RWPF) at DMA Aerospace Center shall be used as the digital image processing system for this experiment It is intended to evaluate feasiblity and practicality by processing test images through the pattern recognition algorithms on the RWPF to classify as many MC&G features as they are capable of and to then complete the feature analysis process in an interactive mode. The feature analysis process consists of detection, identification, classification, and delineation of MC&G features within an image to meet specific product specifications. The evaluation of feasibility and practicality shall be by comparision of present manual/hardcopy methods with semi-automated/softcopy methods.

Results are planned to be published in late 1982. DMA is looking to the results to provide valuable information for use in formulation of requirements for future systems to support the feature analysis functions in the two DMA Production Centers.

Digital Photogrammetry

The Digital Photogrammetry experiment is to do further evaluation of elements of the Image Mensuration and Transfer experiment and to investigate other digital photogrammetric functions.

As a result of the Image Mensuration and Transfer experiment, further evaluation of softcopy stereoscopic mensuration using the anaglyphic method is required. This experiment is to use the DMA Remote Work Processing Facility (RWPF) to do softcopy stereoscopic mensuration using anaglyphic and optical methods to evaluate subjective and objective benefits of each method. This experiment is to evaluate mutiple sensor types and "unclean" imagery; e.g., non-vertical, below normal density, and resolution. The experiment will evaluate effects of image pixel size on mensuration accuracy. Lastley, the experiment is to evaluate an existing image correlation routine to derive digital terrain elevation data within the requirements of the DMA product specificaitons.

Results are planned for late 1982. As with the Feature Analysis experiment, DMA is looking to these results to provide valuable information for use in formulation of requirements for future systems to support the digital photogrammetric function in the two DMA production centers.

Product Generation

The Product Generation experiment is to produce as a result of the Feature Analysis and Digital Photogrammetry experiments "mini-products" related to these two functior

areas. The mini-products will be evaluated against DMA product standards and the digital process used to develop these products will be evaluated against existing production stands to determine feasibility and practicality of these processes being used in the future. Included in the evaluation processes will be a determination of what processes require additional development, technically or procedurally to become acceptable for product; and a determination regarding the time frame that DMA can look to have practical and feasible processes.

Change Detection

A function of a DMA digital production system is to extract useful MC&G information from incoming image data. The prospect of collecting a large volume of image data necessitates the implementation of an efficient automated Change Detection (CD) operation. The CD operation will be used for the evaluation of images and for extraction of the coordinates of change. At the evaluation stage in the digital productions system, the potential usefulness of the incoming image data will be partially determined by the location of changes. At the extraction stage (accomplished perhaps at a later point in the production process) the regions of change in the image data are analyzed for MC&G significant features.

The purpose of this experiment is to compare several current CD techniques (algorithms) available in the image processing community used to delineate areas of land cover change. Evaluation criteria are which.processing technique is the simplest to compute with minimal analytic effort, economically feasible, and the most applicable technique for monitoring land use change.

Those anticipated psychological effects which could impact man/machine interaction during CD processing are being addressed.

One of the primary objectives of CD techniques testing is to determine the applicability to near-term MC&G mission requirements, as well as its impact on future MC&G requirements.

Image Correlation

Image Correlation (IC) plays a major role in the current DMA Production System. Several paradigms are currently in use Stereo Image to Image Transfer is to support basic control point identification for the analytical triangulation process. Another process is point transfer between images. These image processes are completely manual at the moment.

Stereo Computations exists for both manual and automated methods. In Manual mode, the human mind is perceiving three dimensions by viewing images which have stereo overlap through an optical train. Automated methods involve the machine correlating conjugate image points in a stereo pair and determining local x-parallex in order to establish heighting (elevation) information.

The issue of accurate image correlation is of great concern to DMA. Over the years, there have been several correlation schemes devised and are documented in the literature. Many of the schemes are digital in nature. DMA currently uses both digital and analogue with an acceptable degree of success. However, more sophistocated versions are required.

The objectives of this experiment is to evaluate candidate programs/algorithms utilizing IC techniques considered applicable to digital processing of MC&G data.

The algorithms to be tested are two Dimensional Digital Array Correlation, one dimensional Digital (Epipolar Line) Correlation, and Feature Extraction Correlation. Factors fo interest are the cost of techniques with respect to hardware/software requirements, computer time, and human effort, the effectiveness of techniques with respect to image scale and gray level variations, the matching errors and effects on point position determination, and the effectiveness of techniques with respect to decompressed images.

Human Factors Considerations Experiment

The Human Factors Consideration (HFC) Experiment is to consolidate the requirements of the Functional Operation Experiments in terms of hardware/software/control structures (prodcedures)/human factors. There are two explicit objectives of the HFC:

a. To consider hardware/software needs and operator interaction in the appraisal of requirements for an all digital work station environment.

b. To evaluate the following work station requirements:

- Pseudo-color Evaluation

- Display System Evaluation

- Human Engineering

- Work Station Factors

- Digitizing Configurations

- Stereo Techniques

- Functional Software Requriements per each Production Scenario

- Computational Environment Requirements

- User-friendliness

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Screening and Assessment

Screening and Assessment (SA) of source material is a major function within the DMA production activity. DMA is currently investigating the feasibility and practicality of performing the SA function in an all digital environment. The current SA function is mostly a manual operation with little or no computer assisted aids. This experiment is to use the Remote Work Processing Facility (RWPF) and the extensive library of software modules being assembled through the DMA Research and Development Program which are on the RWPF. The RWPF represents the state-of-the-art (SOTA) for digital processing environments.

The objectives of this experiment are:

Establish documentation of the current production process for SA which shows input, process, output, and throughput time (work breakdown analysis) which will be used as a baseline for comparison to validate practicality.

Document the assessment criteria used for source material entering the evaluation process which will be used to model the SA function on the RWPF.

Document the hardware, software, and human factors reqiurements and control structures used to model the SA function in an all digital environment. The SA experimenters will select a test site which is representative of DMA's product reqirements. Evaluations and procedures will be analyzed and a transition of the SA procedures to a digital environment will be assessed.

Early priorities will be to establish and validate the current (baseline) SA production process and the assessment criterias used at each critical point in the SA activity. A subset of the total production SA problem will be identified which is representative of the SA process and which is also emenable to an all digital environment. Control structures will be established which will use the

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modules from the RWPF Library, guided by the results of the previous PDO experiments.

Temporal Normalization

Temporal Normalization (TN) is a new concept to the DMA technical environment. It is an outgrowth of DMA's definitive attempt to demonstrate feasibility and practicality (cost effective with existing processes/increased productivity through automation/extended capability) of achieving an all digital production process. The use of TN in the all digital production domain is viewed at the moment as a preprocessing step before digital Change Detection (CD). It is hoped that the process of "normalizing" the images (defined infollowing paragraph) will increase the "accuracy" of the CD process (decrease the false alarm rate) which will aid in the separation of noise (unuseable information) and information (DMA defined features of concern). Further, TN may aid the cartographer/hydrographer in the extraction of information by providing a more "useful" image.

The definition of TN in the general sense is the elimination of all anomolies (time-varying perturbations) of an image caused by solar angle, atmospheric physics (weather dynamics, optical thickness, single scattering albedo (aerosols), surface albedo (bidirectional reflectance for man made objects), scattering phase function, modulation transfer function), perspecitve (look angle), and seasonal changes. This experiment, like all PDO Experiments, are restricted to state-of-the-art (SOTA) technology. Clearly, the SOTA will not support this definition. Therefore, this experiment considers only perspective, solar angle, and simplistic atmospheric physics model (s).

The objectives of this series of experiments are to determine:

    a. To what degree is TN (constrained to DMA requirements) of imagery possible using available SOTA technology; and,

    b. In what areas is R&D required to support DMA requirements.

Summary

The Pilot Digital Operations is a major experimental activity on the part of DMA to test the feasability and desirability of performing MC&G production processes in the digital domain. Additional benefits include technology transfer, input to prototype system specifications and identification of where further research and development is required. The experiments proceed from an examination of basic image processing to performing MC&G production functions in the digital domain to producing a typical DMA product. Also being investigated are some key support issues. All the experiments will be completed by December 1982.

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